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Procedia Engineering 8 (2011) 360–365

Engineering Procedia

2nd International Science, Social Science, Engineering and Energy Conference 2010: Engineering Science and Management

Generation of DSA for Security Application

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Elsevier use only: Received 15 November 2010; revised 15 December 2010; accepted 20 December 2010

Abstract

A novel system of dark soliton array (DSA) for secured communication generated by using the multiplexed dark soliton pulses is proposed. The multi soliton pulses with relevant parameters are input into the micro ring resonators system with the radii of 10 μm and 5 μm. The dynamic dark solitons can be controlled and generated. The DSA are obtained by using a series micro ring resonators with parameters where in the wavelength range of λ_1 is 15016 nm, λ_2 is 1518 nm and λ_3 is 1520 nm. For security applications, the DSA can be tuned and amplified. Thus, the use of DSA for high capacity transmission can be realized by using proposed secured system. In transmission, the long distance link of the multi variable network can be performed by this DSA.

Key words: Dark solition array, Micro ring resonator, Nonlinear behavior.

1. Introduction

Soliton communication has been a successful system for long distance optical communication links. The required minimum repeater in the link is the key advantage in terms of system performance. However, in practice, the problems of soliton–soliton interaction, soliton collision, and dispersion management must be solved [1–2]. Generally, there are two types of soliton, known as bright and dark solitons [4]. The soliton behaviors and applications are well analyzed and described by Agarwal [5]. In principle, the detection of dark solitons is extremely difficult. To date, several papers have investigated dark soliton behaviors [5–6], and one of them shows an interesting result: that the dark soliton can be converted into a bright soliton and finally detected. This means that the dark soliton penalty can be used as communication security so that it can be retrieved by the dark– bright soliton

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doi:10.1016/j.proeng.2011.03.067

conversion [7, 8]. Recently, a localized soliton pulse was used to produce fast switching [9]. Within a nano waveguide [10, 11], it was reported that the authors designed a system that consists of microring and nanoring resonators. Since then, the use of dark soliton behavior has become a promising application in which the transmission dark soliton can be converted into a bright soliton after passing through a specific add/drop filter [11]. This means that the transmission signals can be transmitted in the form of dark solitons which is difficult to detect. The specific end user that connects to the link via the specific add/drop filter can obtain the signals. Although dark soliton applications have been widely investigated in various applications [12–13], the search for new techniques and more available applications still remains.

2. Operating Principle

An optical soliton can be used to enlarge the optical bandwidth when propagating within the nonlinear micro ring resonator. The superposition of self-phase modulation (SPM) soliton pulses can maintain the large output power. Initially, the optimum energy is coupled into the waveguide by the larger effective core area device of the ring resonator. Then the smaller ring resonator is connected to form the stopping behavior. The filtering characteristic of the optical signal is presented within a ring resonator. Suitable parameters are used to obtain the required output energy. To maintain the soliton pulse propagating within the ring resonator, the right coupling power is set into the device. The interference signal is negligible as compared to the loss associated to the direct passing through. We are looking for a stationary soliton pulse, which is introduced into the a micro ring or a multi-stage micro ring resonator system as shown in Fig. 1. The input optical field (E_{in}) of the dark soliton pulse input is given by

$$E_{in} = A\tanh\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right] \tag{1}$$

where A and z are the optical field amplitude and propagation distance, respectively. T is a soliton pulse propagation time in a frame moving at the group velocity, $T = t-\beta_1 * z$, where β_1 and β_2 are the coefficients of the linear and second order terms of Taylor expansion of the propagation constant. $L_D = T_0^2 / |\beta_2|$ is the dispersion length of the soliton pulse. T_o in Equation (1) is a soliton pulse propagation time at initial input in which t is the soliton phase shift time and the frequency shift of the soliton is ω_0. This solution describes a pulse that keeps its temporal width invariance as it propagates, and thus is called a temporal soliton. When a soliton peak intensity $\left(|\beta_2 / \Gamma T_0^2|\right)$ is given, then T_o is known. For the soliton pulse in the micro ring device, a balance should be achieved between the dispersion length (L_D) and the nonlinear length $L_{NL} = 1/\Gamma\phi_{NL}$, where $\Gamma = n_2 * k_0$, is the length scale over which dispersive or nonlinear effect makes the beam becomes wider or narrower. For a soliton pulse, there is a balance between dispersion and nonlinear lengths, hence $L_D = L_{NL}$.

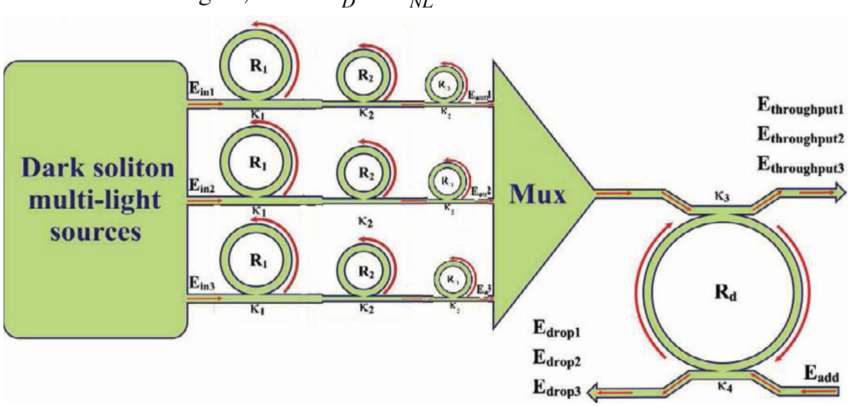

Fig. 1: Schematic of soliton array generation with dark soliton input, where R: ring radii, κ: coupling coefficient, MUX: optical multiplexer

When light propagates within the nonlinear material (medium), the refractive index (n) of light within the medium is given by

$$n = n_0 + n_2 I = n_0 + (\frac{n_2}{A_{eff}})P \tag{2}$$

where n_0 and n_2 are the linear and nonlinear refractive indexes, respectively. I and P are the optical intensity and optical power, respectively. The effective mode core area of the device is given by A_{eff} . For the micro ring and nano ring resonators, the effective mode core areas range from 0.50 to 0.1 μm^2 [5].
A soliton pulse is input and propagates within a micro ring resonator as shown in Fig. 1, consisting of a series micro ring resonators. The resonant output formed has normalized light output which is the ratio between the output and input fields ($E_{out}(t)$ and $E_{in}(t)$) in each roundtrip. This can be expressed as

$$\left|\frac{E_{out}(t)}{E_{in}(t)}\right|^2 = (1-\gamma)\left[1-\frac{(1-(1-\gamma)x^2)\kappa}{(1-x\sqrt{1-\gamma}\sqrt{(1-\kappa)})^2+4x\sqrt{1-\gamma}\sqrt{1-\kappa}\sin^2(\frac{\phi}{2})}\right] \tag{3}$$

The close form of Equation (3) indicates that a ring resonator in this particular case is very similar to a Fabry-Perot cavity, which has an input and output mirror with a field reflectivity, (1-κ), and a fully reflecting mirror. κ is the coupling coefficient, and $x = \exp(-\alpha L/2)$ represents a roundtrip loss coefficient, $\phi_0 = kLn_0$ and $\phi_{NL} = kLn_2|E_{in}|^2$ are the linear and nonlinear phase shifts, $k = 2\pi/\lambda$ is the wave propagation number in a vacuum. L and α are the waveguide length and linear absorption coefficient, respectively. In this work, the iterative method is introduced to obtain the results described by Equation (3) and similarly, when the output field is connected and input into the other ring resonators.

After the signals are multiplexed with the generated chaotic noise, then the chaotic cancellation is required by the individual user. To retrieve the signals from the chaotic noise, we propose to use the add/drop device with the appropriate parameters. The optical circuits of ring-resonator add/drop filters for the throughput and drop port can be given by Equations (4) and (5), respectively [13].

$$\left|\frac{E_t}{E_{in}}\right|^2 = \frac{(1-\kappa_1)-2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_nL)+(1-\kappa_2)e^{-\alpha L}}{1+(1-\kappa_1)(1-\kappa_2)e^{-\alpha L}-2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_nL)} \tag{4}$$

$$\left|\frac{E_d}{E_{in}}\right|^2 = \frac{\kappa_1\kappa_2 e^{-\frac{\alpha}{2}L}}{1+(1-\kappa_1)(1-\kappa_2)e^{-\alpha L}-2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_nL)} \tag{5}$$

where E_t and E_d represents the optical fields of the throughput and drop ports respectively. $\beta = kn_{eff}$ is the propagation constant, n_{eff} is the effective refractive index of the waveguide and the circumference of the ring is $L = 2\pi R$, here R is the radius of the ring. In the following, new parameters will be used for the purpose of simplification with $\phi = \beta L$ as the phase constant. The chaotic noise cancellation can be managed by using specific parameters of the add/drop device in which the required signals can be retrieved by the specific users. κ_1 and κ_2 are coupling coefficient of add/drop filters, $k_n = 2\pi/\lambda$ is the wave propagation number in a vacuum, and the waveguide (ring resonator) loss is α = 0.5 dBmm^{-1}. The fractional coupler intensity loss is γ = 0.1. In the case of add/drop device, the nonlinear refractive index is neglected.

3. Theoretical Result

In simulation, the generated dark soliton pulse, for instance, with 50 ns pulse width and a maximum power of 0.65W, is input into each ring resonator system with different center wavelengths, as shown in Fig. 1. Suitable ring parameters are used, such as ring radii and ring coupling coefficients of R_1 = 7 µm, R_2 = 5 µm and R_3 = 2.5 µm. To make the system associate with the practical device [14], $n_0 = 3.34$ (In- GaAsP/InP). The effective core areas are A_{eff} = 0.50, 0.25 and 0.1µm^2 for MRRs. The waveguide and coupling losses are α = 0.5 dBmm^{-1} and γ = 0.1, respectively, and the coupling coefficients κ of the MRRs range from 0.01 to 0.975. The nonlinear refractive index is $n_2 = 2.2 \times 10^{-13}$m^2/W. In this case, the waveguide loss used is 0.5 dBmm^{-1}. The input dark soliton pulse is chopped into smaller signals R_1, R_2 and R_3 and the filtering signals within add/drop ring R_d are seen. We find that the output signal from R_3 is larger than that from R_1 due to the different core effective areas of the rings in the system. However, the effective areas can be transferred from 0.50, 0.25 and 0.10µm² with some losses. The soliton signals in R_d enter the add/drop filter, where the dark soliton conversion can be performed by using Eqs. (4) and (5).

In this application, a different dark soliton wavelength is input into the MRR system and the parameters of the system are unchanged. For instance, the dark solitons are input into the system at the center wavelengths λ_1 = 1516, λ_2 = 1518, and λ_3 = 1520 nm. When a dark soliton propagates into the MRR system, the occurrence of dark soliton collision (modulation) in the MUX system and the filtering signals within the add/drop ring (R_d) are as shown in Fig. 1. The dark soliton is generated by multilight sources at the center wavelength λ_1 = 1516nm and the filtering signals are as shown in Fig. 2. Similary Fig. 3 and 4 shows the results for different center wavelength of 1518 nm and 1520 nm.

Fig. 5 shows the dark soliton array generated by multilight sources at center wavelengths of λ_1 = 1516, λ_2 = 1518, and λ_3 =1520 nm together with the filtering signals.

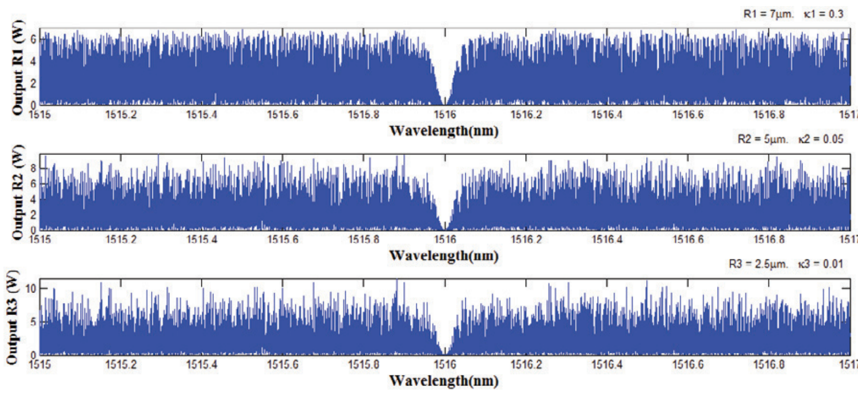

Fig. 2: Simulation result of dark soliton output from the ring R_1, R_2 and R_3 with the center wavelength of 1516nm.

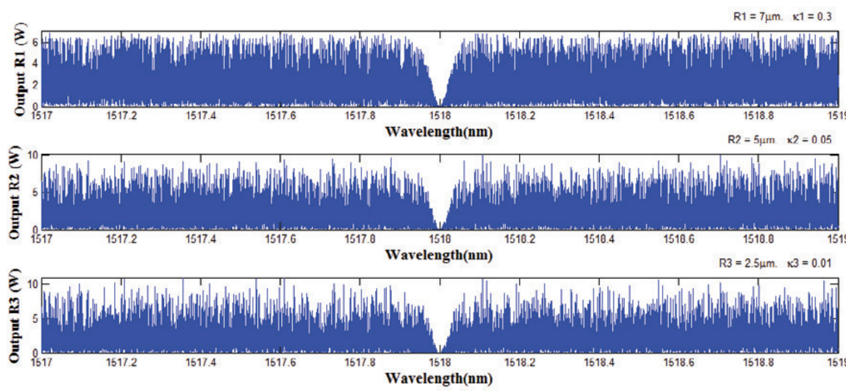

Fig. 3: Simulation result of dark soliton output from the ring R_1, R_2 and R_3 with the center wavelength of 1518nm.

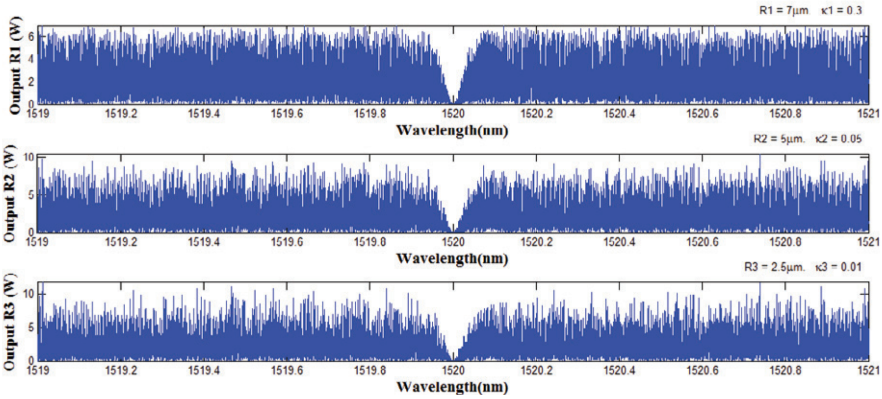

Fig. 4: Simulation result of dark soliton output from the ring R_1, R_2 and R_3 with the center wavelength of 1516nm.

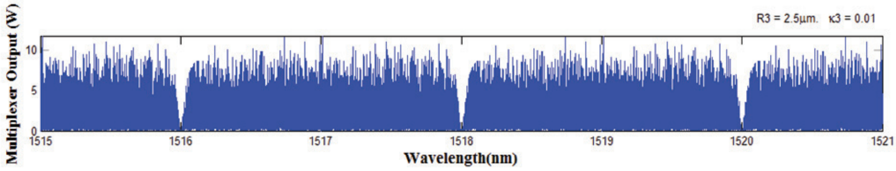

Fig. 5: Simulation results of the dynamic optical trapping array within micro ring resonators, where multiplex wavelengths are λ_1=1516nm, λ_2=1518nm and λ_3=1520nm.

4. Conclusion

The proposed system for secured communication consists of series of micro ring resonators that can be integrated into a single system, which can then be employed to overcome the problem of bandwidth delay constraints for small group velocities. The large bandwidth is generated by a soliton pulse within a Kerr type nonlinear medium where all optical adiabatic and reversible pulse bandwidth compression can be performed. The balance between dispersion and nonlinear lengths of the soliton pulse exhibits the soliton behavior known as SPM. The large signal amplification due to the effects of a dark soliton pulse gives an unexpected applications in this proposed system for the use of signal in long distance secured communication and network can be performed. This is further enhanced by the chaotic signal generation using a soliton pulse in the nonlinear micro ring resonators with high coupling power of soliton pulse for secured transmission.

The advantage of the system is that the clear signal can be retrieved by the specific add/drop filter, which is now commercially available and the optical communication capacity can be increased by the multi-soliton communication. This provides more soliton channels being generated using the micro ring system. The required channels are obtained by filtering the large bandwidth signals using the add/drop multiplexer, which again is formed by using the micro ring device.

5. Acknowledgements

We would like to thank the Institute of Advanced Photonics Science, Nanotechnology Research Alliance, Universiti Teknologi Malaysia (UTM) and King Mongkut's Institute of Technology (KMITL), Thailand for the support in research facilities. This research work has been supported by the Ministry of Higher Education (MOHE), FRGS-grant 78452.

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